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Hoshizuki

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(54) **ENCRYPTION PROCESSING SYSTEM, ENCRYPTION PROCESSING DEVICE AND RECORDING MEDIUM**

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H04L 9/06	(2006.01)

(52) **U.S. Cl.**

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(58) **Field of Classification Search**

CPC ... H04L 9/008; H04L 9/0618; H04L 63/0428; H04L 2209/46

See application file for complete search history.

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(57) **ABSTRACT**

An encryption processing system includes: an encryption data generation device, an encryption processing device, and a processing result utilization device. A first processor of the encryption data generation device is configured to perform preprocessing by generating encrypted data of homomorphic encryption corresponding to data obtained by multiplying plaintext data as a target by a power of a predetermined number of two or more. A second processor of the encryption processing device is configured to perform acquiring the encrypted data, and executing a processing on the encrypted data in an encrypted state to obtain a processing result in the encrypted state. A third processor of the processing result utilization device is configured to perform acquiring the processing result, and postprocessing by decrypting data of the processing result in the encrypted state and by dividing the decrypted data by the power of the predetermined number of two or more.

8 Claims, 8 Drawing Sheets

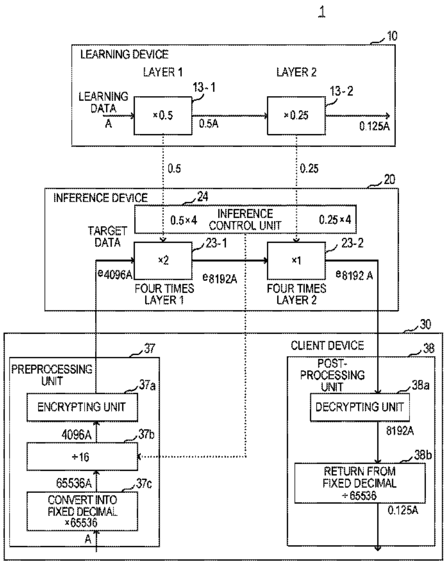

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FIG. 1

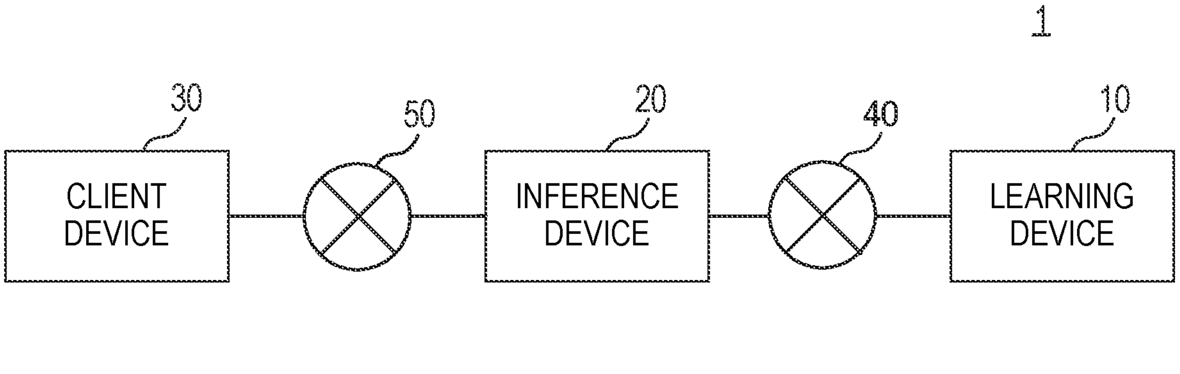

1
30
CLIENT DEVICE
50
20
INFERENCE DEVICE
40
10
LEARNING DEVICE

FIG. 2

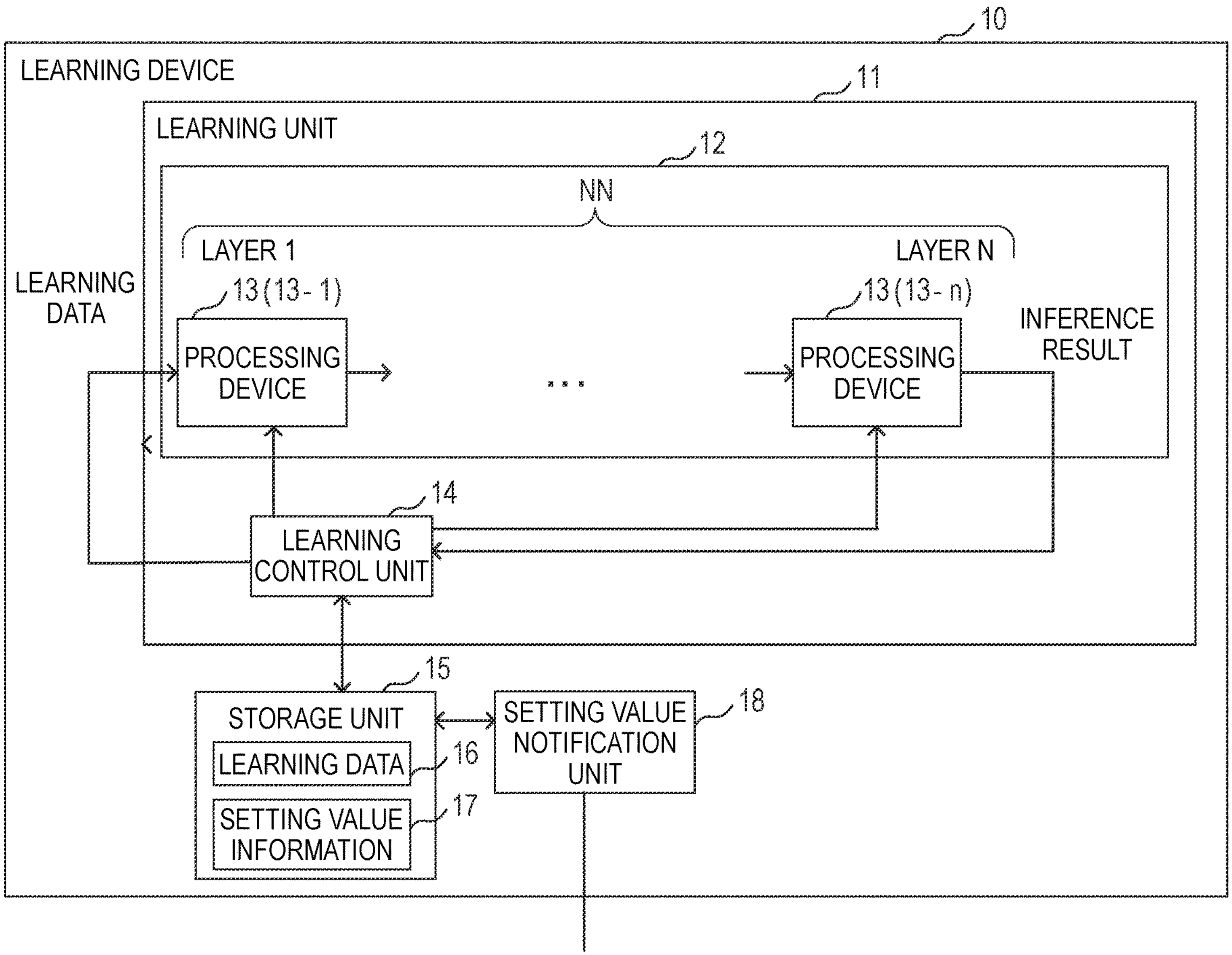

10
LEARNING DEVICE
11
LEARNING UNIT
12
NN
LAYER 1
LAYER N
LEARNING DATA
13 (13 - 1)
PROCESSING DEVICE
...
13 (13 - n)
PROCESSING DEVICE
INFERENCE RESULT
14
LEARNING CONTROL UNIT
15
STORAGE UNIT
LEARNING DATA
16
SETTING VALUE INFORMATION
17
SETTING VALUE NOTIFICATION UNIT
18

FIG. 3

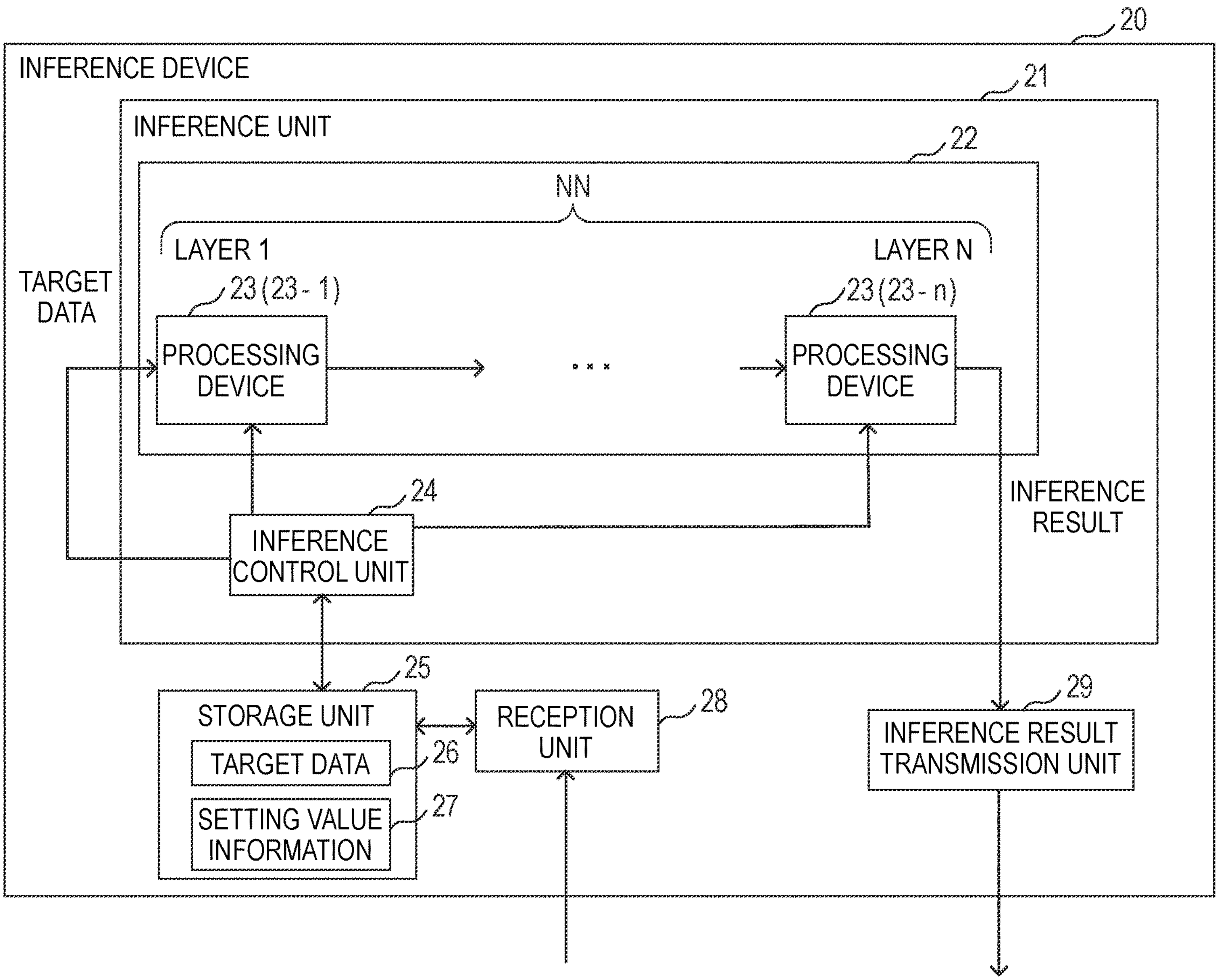

20
INFERENCE DEVICE
21
INFERENCE UNIT
22
NN
LAYER 1
LAYER N
TARGET DATA
23 (23 - 1)
PROCESSING DEVICE
• • •
23 (23 - n)
PROCESSING DEVICE
24
INFERENCE CONTROL UNIT
INFERENCE RESULT
25
STORAGE UNIT
TARGET DATA
26
SETTING VALUE INFORMATION
27
RECEPTION UNIT
28
29
INFERENCE RESULT TRANSMISSION UNIT

FIG. 4

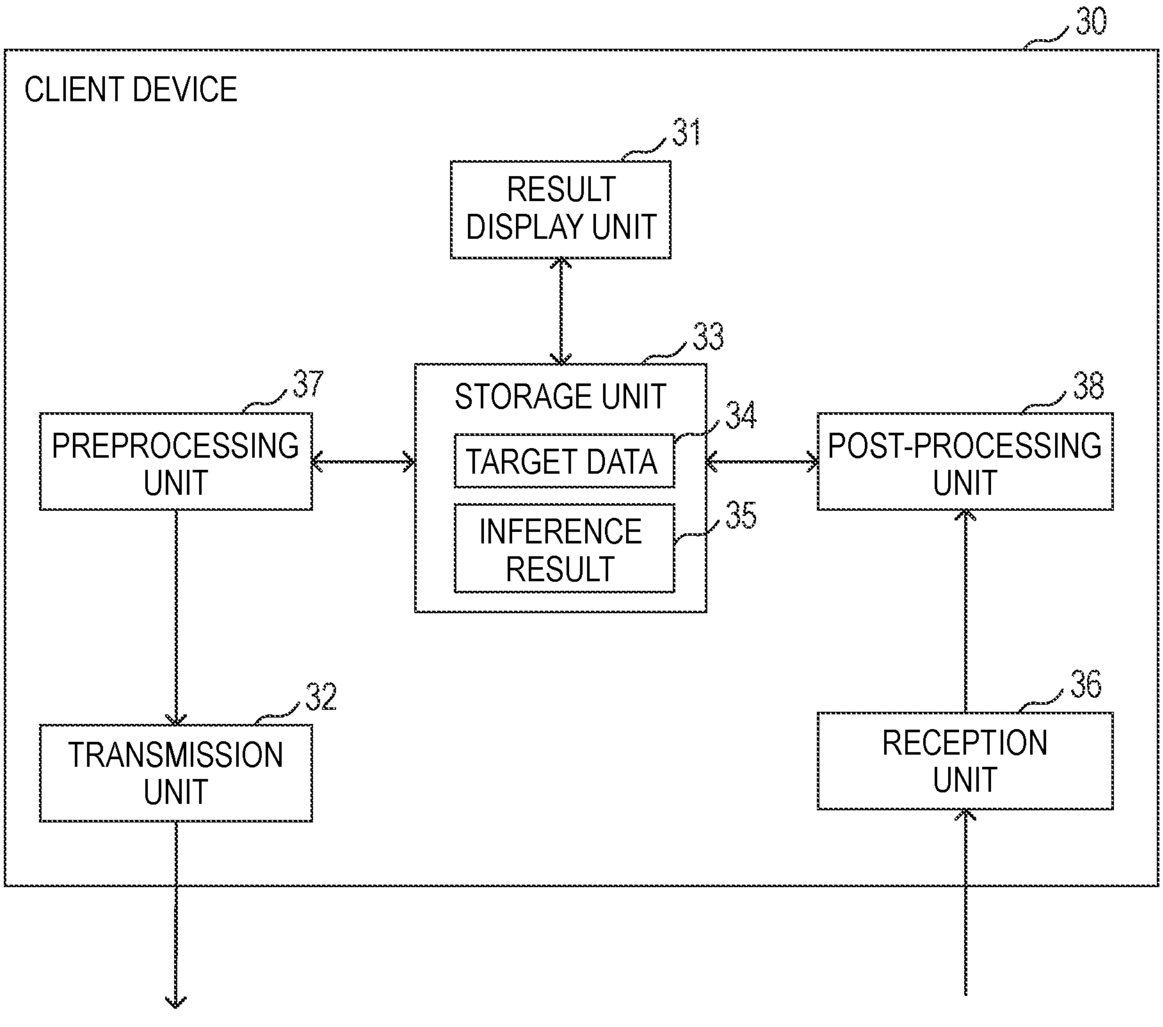

30
CLIENT DEVICE
31
RESULT DISPLAY UNIT
33
STORAGE UNIT
34
TARGET DATA
35
INFERENCE RESULT
37
PREPROCESSING UNIT
38
POST-PROCESSING UNIT
32
TRANSMISSION UNIT
36
RECEPTION UNIT

FIG. 5

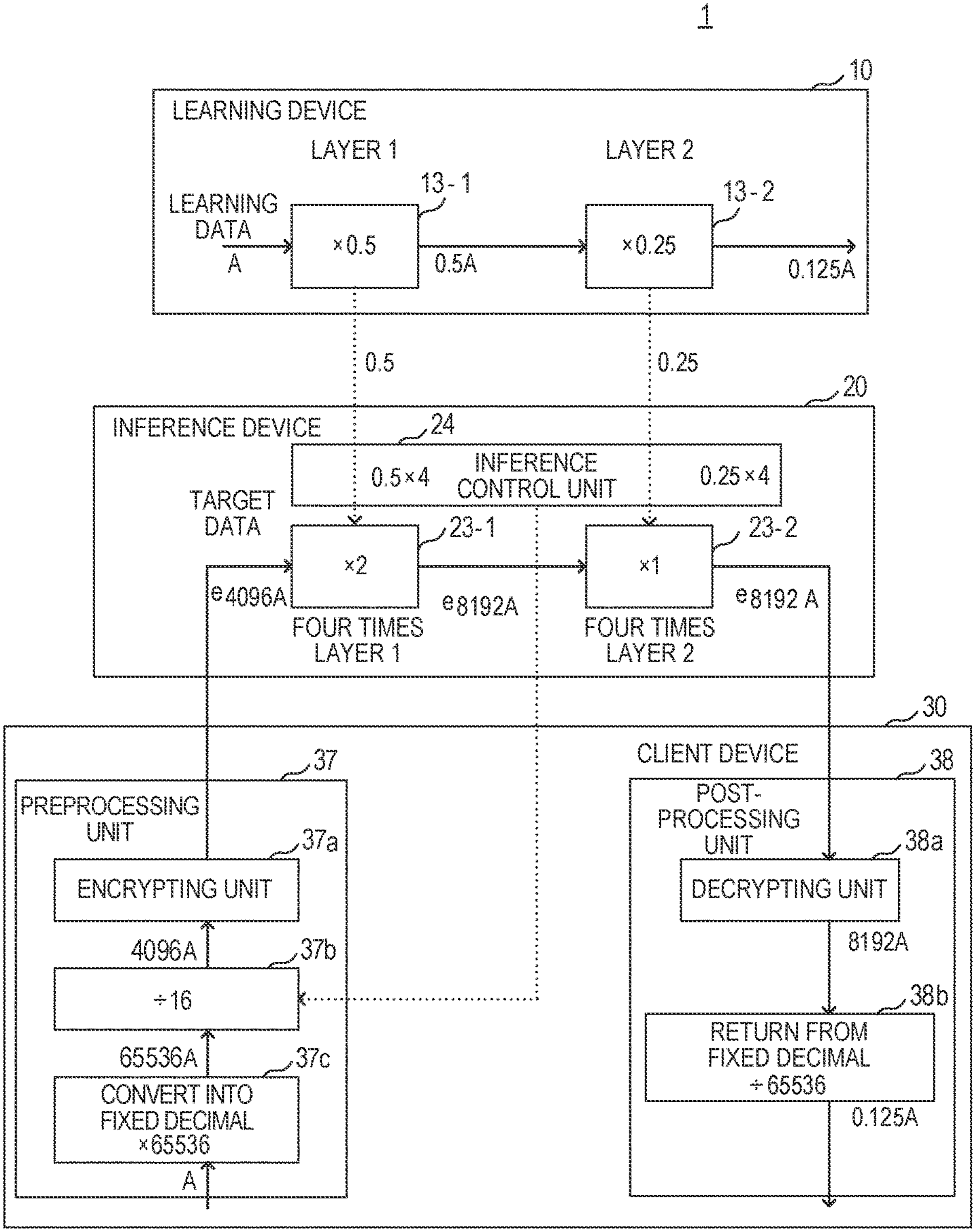

1
10
LEARNING DEVICE
LAYER 1
LAYER 2
13-1
13-2
LEARNING DATA
A
×0.5
0.5A
×0.25
0.125A
0.5
0.25
20
INFERENCE DEVICE
24
0.5×4
INFERENCE CONTROL UNIT
0.25×4
TARGET DATA
23-1
23-2
×2
×1
e4096A
e8192A
e8192 A
FOUR TIMES LAYER 1
FOUR TIMES LAYER 2
30
CLIENT DEVICE
37
PREPROCESSING UNIT
37a
ENCRYPTING UNIT
4096A
37b
÷16
65536A
37c
CONVERT INTO FIXED DECIMAL ×65536
A
38
POST-PROCESSING UNIT
38a
DECRYPTING UNIT
8192A
38b
RETURN FROM FIXED DECIMAL ÷65536
0.125A

FIG. 6

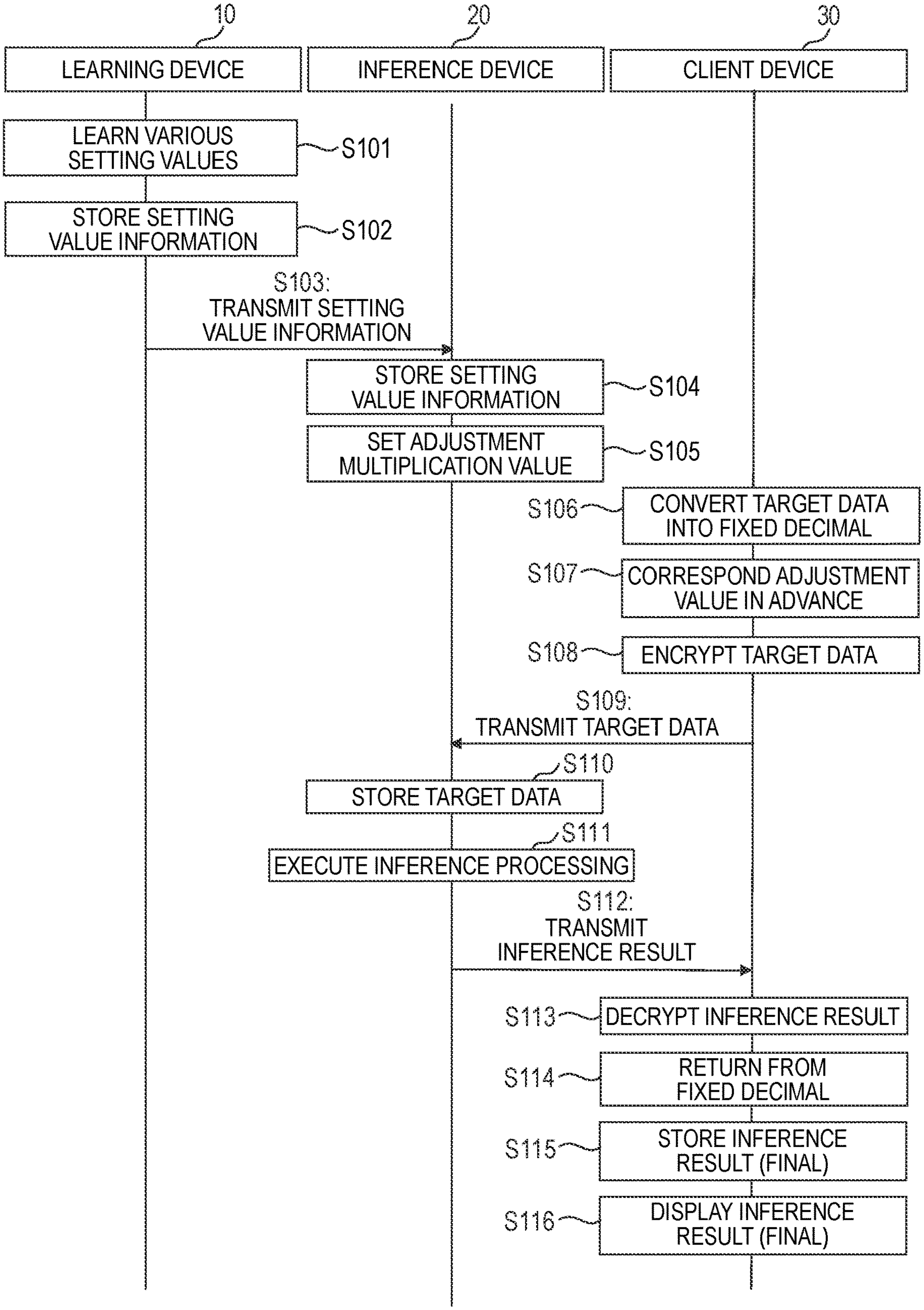

10
20
30
LEARNING DEVICE
INFERENCE DEVICE
CLIENT DEVICE
LEARN VARIOUS SETTING VALUES
S101
STORE SETTING VALUE INFORMATION
S102
S103: TRANSMIT SETTING VALUE INFORMATION
STORE SETTING VALUE INFORMATION
S104
SET ADJUSTMENT MULTIPLICATION VALUE
S105
S106
CONVERT TARGET DATA INTO FIXED DECIMAL
S107
CORRESPOND ADJUSTMENT VALUE IN ADVANCE
S108
ENCRYPT TARGET DATA
S109: TRANSMIT TARGET DATA
S110
STORE TARGET DATA
S111
EXECUTE INFERENCE PROCESSING
S112: TRANSMIT INFERENCE RESULT
S113
DECRYPT INFERENCE RESULT
S114
RETURN FROM FIXED DECIMAL
S115
STORE INFERENCE RESULT (FINAL)
S116
DISPLAY INFERENCE RESULT (FINAL)

FIG. 7

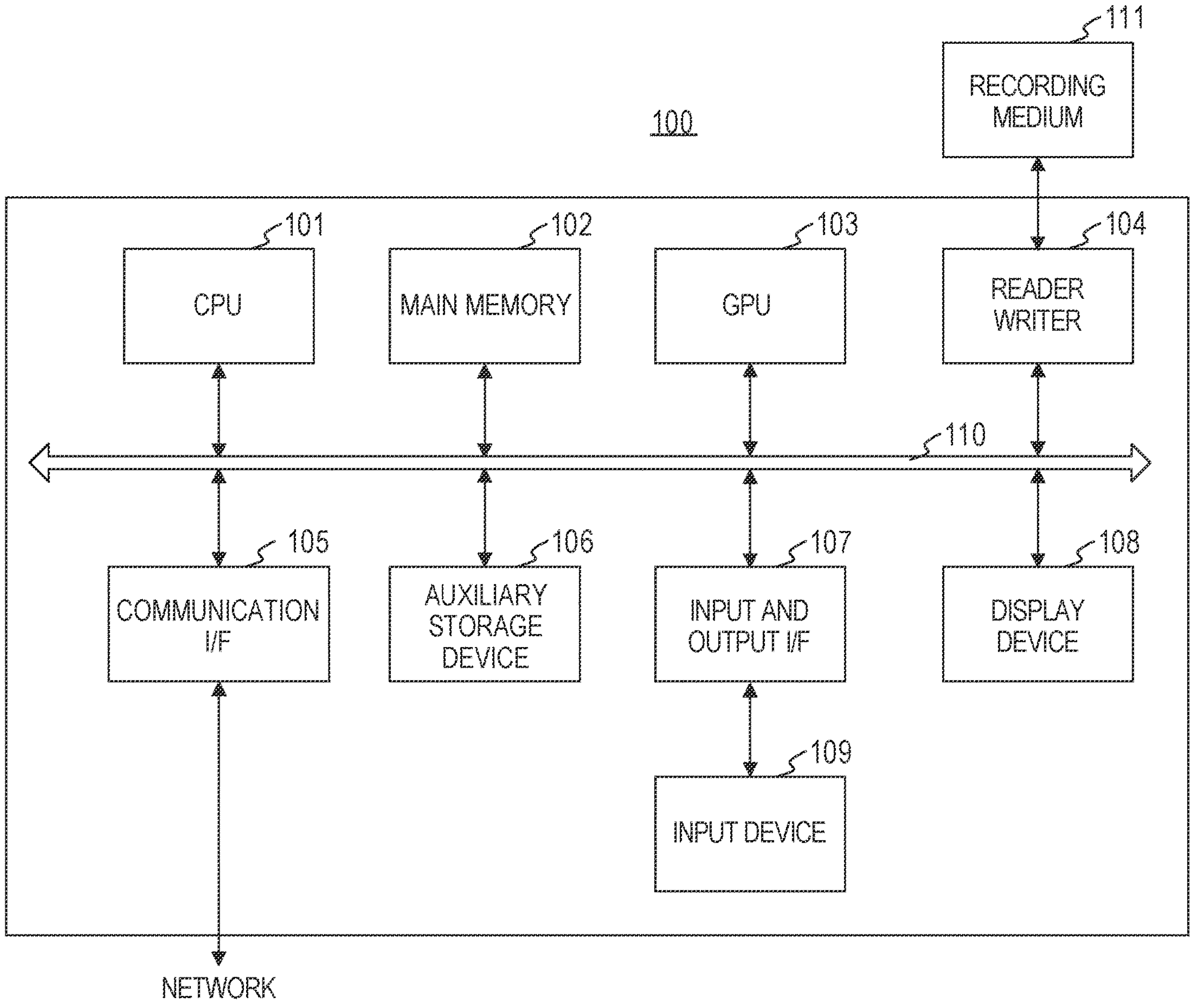
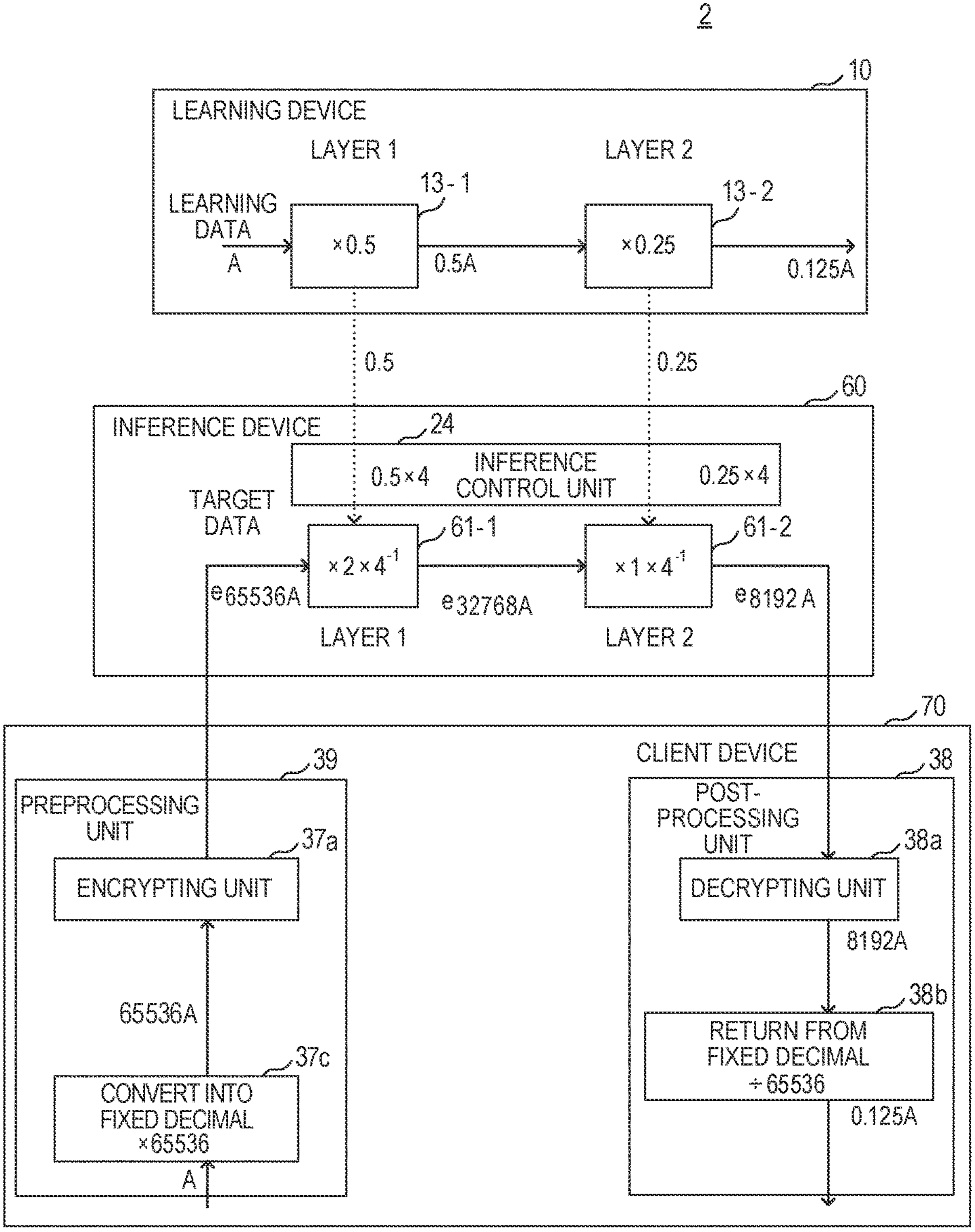

100
111
RECORDING MEDIUM
101
CPU
102
MAIN MEMORY
103
GPU
104
READER WRITER
110
105
COMMUNICATION I/F
106
AUXILIARY STORAGE DEVICE
107
INPUT AND OUTPUT I/F
108
DISPLAY DEVICE
109
INPUT DEVICE
NETWORK

FIG. 8


2
10
LEARNING DEVICE
LAYER 1
LAYER 2
13-1
13-2
LEARNING DATA
A
×0.5
0.5A
×0.25
0.125A
0.5
0.25
60
INFERENCE DEVICE
24
0.5×4
INFERENCE CONTROL UNIT
0.25×4
TARGET DATA
61-1
61-2
×2×4⁻¹
×1×4⁻¹
e65536A
e32768A
e8192 A
LAYER 1
LAYER 2
70
CLIENT DEVICE
39
PREPROCESSING UNIT
37a
ENCRYPTING UNIT
65536A
37c
CONVERT INTO FIXED DECIMAL ×65536
A
38
POST-PROCESSING UNIT
38a
DECRYPTING UNIT
8192A
38b
RETURN FROM FIXED DECIMAL ÷65536
0.125A

ENCRYPTION PROCESSING SYSTEM, ENCRYPTION PROCESSING DEVICE AND RECORDING MEDIUM

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the benefit of priority of the prior Japanese Patent Application No. 2019-095289, filed on May 21, 2019, the entire contents of which are incorporated herein by reference.

BACKGROUND

Technical Field

The embodiments discussed herein are related to preventing data leakage and executing a wide range of processing.

Related Art

A neural network model as a machine learning architecture has been used to perform recognition processing (inference processing) of images, characters, sounds, and the like.

Coefficient data that has been learned in the neural network model is large in scale. If the processing is performed only on a client device, a load may be large or it may be difficult to execute the processing. Therefore, it is desired to use a cloud resource, which can perform large-scale operations by using a server-client model, for the inference processing using the neural network model.

When the server-client model is used, data to be processed is transmitted from a client device to a server, so that highly confidential data such as personal information included in the data may be leaked.

In order to address such a problem, it is conceivable to use a confidential operation method which performs operations while the data is encrypted. Broadly speaking, as for the confidential operation method, there is a method using homomorphic encryption and a method using multi-party-computation (MPC).

First, the method using the homomorphic encryption will be described.

The homomorphic encryption refers to an encryption method in which a set of a ciphertext and an operation having a homomorphic relationship with a plaintext and a certain operation exists. Strictly speaking, the homomorphic encryption is an encryption method which has a function G satisfying Enc(F(a, b))=G(C1, C2), in which Enc refers to an encryption function with respect to plaintexts a, b and a two-variable function F(a, b) thereof, while there is a ciphertext c1=Enc(a) and a ciphertext c2=Enc(b).

There are several types of homomorphic encryption, and a case where F(a, b)=a+b is referred to as additive homomorphic encryption (AHE). In practice, even when F(a, b)=a+b mod n, if the plaintext to be handled is sufficiently small, it can be regarded as substantially a+b, so it is also referred to as the additive homomorphic encryption.

A case where F(a, b)=a×b is referred to as multiplicative homomorphic encryption (MHE). In practice, even when F(a, b)=a×b mod n, if the plaintext to be handled is sufficiently small, it can be regarded as substantially a×b, so it is also referred to as the multiplicative homomorphic encryption.

Fully homomorphic encryption (FHE) is known as homomorphic encryption that can handle both addition and multiplication operations. However, the fully homomorphic encryption is considered to be impractical since an amount of computation thereof is enormous as compared with capabilities of currently available computers.

Somewhat homomorphic encryption (SHE) is also known as homomorphic encryption that can handle both addition and multiplication operations, and an amount of computation thereof is reduced by providing an upper limit for the number of times of operations as compared with the fully homomorphic encryption.

For example, the specification of JP-A-2012-49679 discloses a terminal device including: an encrypting unit configured to encrypt data input by a fully homomorphic encryption method and generate encryption data; an encryption data transmitting unit configured to transmit the encryption data generated by the encrypting unit to a server; an encryption data receiving unit configured to receive the encryption data that has been subjected to a predetermined processing by the server; and a decoding unit configured to decode the encryption data which has been subjected to the predetermined processing. According to the technique of JP-A-2012-49679, the processing of input data can be delegated to the server without leaking contents of the input data to be processed to the server

Meanwhile, the MPC refers to a system that operates encrypted data while performing communication using a plurality of computers. The MPC can perform a plurality of types of operations as compared with the homomorphic encryption.

In the neural network model, it may be difficult to process data in the encrypted state since a processing load thereof is heavy. For example, in "Research Article: Oblivious Neural Network Computing via Homomorphic Encryption" by C. Orlandi, A. Piva, and M. Barni, which is available on the Internet <http://clem.dii.unisi.it/~vipp/files/publications/S1687416107373439.pdf), each time an activation function is operated, data is exchanged between a server and a client so as to execute the operation of the activation function on a client side. Therefore, in the technique of Non-Patent Literature 1, an amount of communication between the server and the client is increased, and processing time thereof becomes longer.

In the neural network model, in consideration of processing the data in the state of the encrypted data, the additive homomorphic encryption, whose available operations are limited, may not be able to execute neural network operations. In order to cope with such a problem, it is also conceivable to use the fully homomorphic encryption or the somewhat homomorphic encryption, which is capable of performing more types of operations. However, since an amount of data of encrypted data using such encryption is large, a processing load during the operation may increase.

Considering the point of reducing the processing load, it is preferable to use the additive homomorphic encryption to perform the processing. However, when the additive homomorphic encryption is used, the available operations are limited, and thus executable processings may be limited. For example, when the additive homomorphic encryption is used, a processing of executing non-integer multiplication (for example, multiplication of a number less than one (equivalent to division) is also included) cannot be executed. For example, in the neural network model, an operation is generally performed using floating-point format decimals. However, since the additive homomorphic encryption has a homomorphic relationship with integers, it seems natural to use fixed-point format decimals therein. However, when a fixed-point format decimal is multiplied, division is required for adjusting the number of bits of the fixed-point format decimal. As described above, since division cannot be performed in the additive homomorphic encryption, as a result, the additive homomorphic encryption cannot be used for data in which fixed-point format decimals are input.

In the case where the additive homomorphic encryption is used to perform the processing, executable processings may also be limited similarly in a processing which does not use the neural network model, besides the processing using the neural network model.

SUMMARY

According to an aspect of the present disclosure, there is provided an encryption processing system including: an encryption data generation device comprising at least one first processor; an encryption processing device comprising at least one second processor; and a processing result utilization device comprising at least one third processor, wherein the at least one first processor is configured to perform preprocessing by generating encrypted data of homomorphic encryption corresponding to data obtained by multiplying plaintext data as a target to be processed, by a power of a predetermined number of two or more, the at least one second processor is configured to perform acquiring the encrypted data from the data generation device, and executing a processing on the encrypted data in an encrypted state to obtain a processing result in the encrypted state, and the at least one third processor is configured to perform acquiring the processing result from the encryption processing device, and postprocessing by decrypting data of the processing result in the encrypted state and by dividing the decrypted data by the power of the predetermined number of two or more.

The object and advantages of the invention will be realized and attained by means of the elements and combinations particularly pointed out in the claims.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory and are not restrictive of the invention, as claimed.

BRIEF DESCRIPTION OF DRAWINGS

Exemplary embodiment(s) of the present invention will be described in detail based on the following figures, wherein:

FIG. **1** is an overall configuration diagram of a processing system according to an embodiment;

FIG. **2** is a functional configuration diagram of a learning device according to the embodiment;

FIG. **3** is a functional configuration diagram of an inference device according to the embodiment;

FIG. **4** is a functional configuration diagram of a client device according to the embodiment;

FIG. **5** is a functional configuration diagram of an example of the processing system according to the embodiment;

FIG. **6** is a sequence diagram showing an operation of the processing system according to the embodiment;

FIG. **7** is a configuration diagram of a computer device according to the embodiment; and

FIG. **8** is a functional configuration diagram of an example of a processing system according to a modified embodiment.

DETAILED DESCRIPTION

Embodiments will be described with reference to the drawings. It should be noted that the embodiments described below do not limit the invention according to the claims, and all of the elements and combinations thereof described in the embodiments are not necessarily essential to the solution to the problem.

First, a processing system according to an embodiment will be described.

FIG. **1** is an overall configuration diagram of the processing system according to the embodiment.

A processing system **1** is an example of an encryption processing system, and includes a learning device **10**, an inference device **20** serving as an example of an encryption processing device, and a client device **30** serving as an example of an encryption data generation device and a processing result utilization device. The learning device **10** and the inference device **20** are connected via a network **40**. The inference device **20** and the client device **30** are connected via a network **50**. The networks **40**, **50** are, for example, local area networks (LAN) or wide area networks (WAN). Although the network **40** and the network **50** are different networks in FIG. **1**, the networks may also be the same network.

The learning device **10** learns a neural network model. The inference device **20** sets the neural network model based on a learning result of the neural network model learned by the learning device **10** (setting values of coefficients (weight or bias) of the neural network model, and the like) and performs an inference processing. The client device **30** is, for example, a device used by a user, and executes a preprocessing, such as encrypting, on data to be subjected to the inference processing (target data). Then the client device **30** transmits the preprocessed data to the inference device **20**. The client device **30** receives a result of the inference processing (inference result) performed by the inference device **20**, executes a post-processing on the encrypted inference result, and obtains a final inference result.

FIG. **2** is a functional configuration diagram of a learning device according to a first embodiment.

The learning device **10** includes a learning unit **11**, a storage unit **15**, and a setting value notification unit **18**.

The learning unit **11** includes a neural network model **12** and a learning control unit **14**.

The neural network model **12** is, for example, a neural network model configured to execute a predetermined inference processing and output an inference result thereof. The neural network model **12** is configured by one or more processing layers (layers). In the present embodiment, the neural network model **12** is used for learning a setting value. In the example of FIG. **2**, the neural network model **12** is configured by layers 1 to N. Here, N is an integer of 1 or more. A processing in each layer is executed by each processing unit **13**. The processing in each layer is an example of a partial processing. The neural network model **12** may be, for example, a model that executes the inference processing to infer what an image data to be processed represents, for example, what is included therein, such as a person, a dog, or a cat, and outputs the inference result. The number of layers in the neural network model **12** and types and contents of the partial processing executed in each layer may be set optionally.

Examples of the processing unit **13** constituting the layer of the neural network model **12** include a convolution processing unit, an activation function unit, a pooling processing unit, an affine processing unit, a SoftMax processing unit, and the like. The convolution processing unit executes a convolution processing using each of a plurality of pieces of filter data (an example of the setting value). The activation function unit executes a processing of converting input data by an activation function. The pooling processing unit executes a processing of down-sampling the input data. The affine processing unit executes an affine transformation processing on the input data. The SoftMax processing unit executes a processing by a soft max function on the input data.

The learning control unit **14** receives the learning data **16** stored in the storage unit **15** and inputs it to the neural network model **12**. The learning control unit **14** learns the setting value in the neural network model **12** based on inference results input to the neural network model **12** and output from the neural network model **12**. When learning of learning data **16** is finished, the learning control unit **14** stores setting value information **17** related to the setting value obtained by the learning in the storage unit **15**.

The storage unit **15** stores the learning data **16** used for the learning unit **11** to learn the neural network model **12** and the setting value information **17**, which is information related to setting values of coefficients and the like of the neural network model **12**. The learning data **16** may be stored in the storage unit **15** as teacher data associated with inference result data corresponding to the learning data **16**. The learning data **16** may be, for example, unencrypted data (plaintext data). The setting value included in the setting value information **17** includes, for example, a filter coefficient used in the convolution processing unit, a weight used in the affine processing unit, and the like, and such values are used as multipliers, for example, in multiplication of the processing unit.

The setting value notification unit **18** transmits the setting value information **17** stored in the storage unit **15** to the inference device **20**.

Next, the inference device **20** will be described in detail. FIG. **3** is a functional configuration diagram of the inference device according to the embodiment.

The inference device **20** includes an inference unit **21** serving as an example of a processing execution unit, a storage unit **25**, a reception unit **28** serving as an example of a first acquisition unit, and an inference result transmission unit **29**.

The inference unit **21** includes a neural network model **22** and an inference control unit **24**.

The neural network model **22** is, for example, a neural network model configured to input encryption data which is encrypted by homomorphic encryption, execute a predetermined inference processing and output an inference result thereof. The homomorphic encryption is, for example, Paillier encryption or lifted-ElGamal encryption.

The neural network model **22** is constituted by one or more processing layers (layers). In the present embodiment, the neural network model **22** is configured to execute processing corresponding to the neural network model **12** of the learning device **10** on encrypted data. In the present embodiment, for example, each processing unit **23** of the neural network **22** corresponds to each processing unit **13** of the neural network **12**. In the example of FIG. **3**, the neural network model **22** is configured by layers 1 to N. A processing in each layer (partial processing) is executed by each processing unit **23**. The neural network model **22** may be, for example, a model that executes the inference processing to infer what an image data to be processed represents, for example, what is included therein, such as a person, a dog, or a cat, and outputs the inference result. The number of layers in the neural network model **22** and types and contents of the partial processing executed in each layer may be set optionally.

Examples of the processing unit **23** constituting the layer of the neural network model **22** include a convolution processing unit, an activation function unit, a pooling processing unit, an affine processing unit, a SoftMax processing unit, and the like.

The inference control unit **24** sets the neural network model **22** based on the setting value information **27** stored in the storage unit **25**, that is, sets coefficients and the like in the processing unit **23** of the processing layer. In the present embodiment, the inference control unit **24** sets an adjustment multiplication value for the processing unit **23** corresponding to the processing unit **13** of the learning device **10** that executes a non-integer multiplication processing. The adjustment multiplication value is an integer obtained by multiplying the setting value indicated by the setting value information **27** by an adjustment value (for example, a number larger than 1) determined in advance for the processing unit **23**. When a result obtained by multiplying the setting value by the adjustment value is not an integer, for example, an integer close to that value may be used as the adjustment multiplication value. As a result, in the processing unit **23**, a ciphertext space operation corresponding to a processing of multiplying plaintext data by the adjustment multiplication value is performed on encrypted data input from a preceding stage. That is, in the processing unit **23**, an operation of multiplying a number, which is the adjustment value times larger (substantially the adjustment value times larger in a case where a value obtained by multiplying the setting value by the adjustment value is not an integer) than that of the processing unit **13**, is performed. For example, in a case where encryption data input to a certain processing unit **23** is encryption data obtained by encrypting plaintext data input to the corresponding processing unit **13**, when a processing result of encrypted data output from the processing unit **23** is decrypted, a value thereof is the adjustment value times larger than that of the processing result of the processing unit **13**.

For example, in a case where the setting value transmitted from the learning device **10** (corresponding to the setting value obtained by the learning of the learning device **10**) is floating-point format data, the inference control unit **24** converts the setting value into fixed-point format data having a predetermined number of bits. Then the inference control unit **24** may multiply the setting value converted to the fixed-point format by the adjustment value and converts a value thereof into an integer to obtain the adjustment multiplication value. At this time, the adjustment value may be a power-of-two adjustment value that may convert fixed-point format data having a predetermined number of bits into an integer. In this way, the adjustment multiplication value may be reliably converted into an integer. In a case where the setting value transmitted from the learning device **10** (corresponding to the setting value obtained by the learning of the learning device **10**) is fixed-point format data, the setting value may be multiplied by the adjustment value so as to be converted into an integer and obtain the adjustment multiplication value.

Here, Paillier encryption, which is an additive homomorphic encryption, will be described as an example of the additive homomorphic encryption.

When a processing related to the encryption is performed, the following various settings are determined. That is, secure prime numbers p and q to be used in the encryption are prepared. Procedures and precautions for determining the prime numbers may be the same as that of RSA encryption. It is assumed that N=p×q. k is optionally set in a range of

1≤k≤N−1. Let g=1+kN. Here, p and q are secret keys, g and N are public keys and system parameters.

For example, when plaintext data is A, B (0≤A≤N−1, 0≤B≤N−1), encrypted data eA, eB obtained by performing encryption respectively are expressed as shown in the following equations (1) and (2):

$$e_A = g^A \times r_1^N \bmod N^2 \tag{1}$$

$$e_B = g^B \times r_2^N \bmod N^2 \tag{2}$$

Here, **r1** (0≤r1≤N−1) and **r2** (0≤r2≤N−1) are random numbers.

An operation corresponding to a sum operation between encrypted data of the Paillier encryption and the plaintext data may be executed as multiplication of the encrypted data.

The multiplication of the encrypted data, that is, eA×eB, is as shown in equation (3):

$$\begin{aligned} e_A \times e_B &= g^A \times g^B \times r_1^N \times r_2^N \bmod N^2 \\ &= g^{A+B} \times r_1^N \times r_2^N \bmod N^2. \end{aligned} \tag{3}$$

Here, since g=(1+kN), $g^N=(1+kN)^N$ can be obtained by substituting (1+kN) into g of g^N. When $(1+kN)^N$ is expanded by the binomial theorem, $(1+kN)^N=1+kN^2+ \ldots$. Since second and subsequent terms of the expression $1+kN^2+ \ldots$ after the expansion are all multiples of N^2, a result of dividing $1+kN^2+ \ldots$ by N^2 is 1. Therefore, $g^N \bmod N^2=1$. Since $g^N \bmod N^2=1$, $g^{(A+B)}=g^{(A+B \bmod N)}$ is established. Then equation (3) may be transformed into the following equation using the relationship of:

$$g^{(A+B)} = g^{(A+BmodN)}. \tag{4}$$

$$\begin{aligned} \text{Equation (3)} &= g^{(A+B\,modN)} \times r_1^N \times r_2^N \bmod N^2 \\ &= g^{(A+B\,modN)} \times (r_1 \times r_2)^N \bmod N^2 \end{aligned}$$

If $r_3=r_1 \times r_2 \bmod N$, since r_1 and r_2 are all random numbers, r_3 is also a random number. Therefore, equation (4) may be transformed as shown in the following equation (5).

$$\begin{aligned} \text{Equation (4)} &= g^{(A+B\,modN)} \times r_3^N \bmod N^2 \\ &= e(A+B \bmod N) \end{aligned} \tag{5}$$

e(A+B mod N) shown in equation (5) becomes A+B mod N when decrypted. Therefore, if A and B are sufficiently smaller than N, the expression can be substantially regarded as A+B, so that the multiplication of the encrypted data corresponds to the sum operation of the plaintext data.

An operation corresponding to multiplication of the plaintext data and an integer of the plaintext data can be executed on the encrypted data of the Paillier encryption.

A×C, which is a multiplication of plaintext data A and integer C, corresponds to a sum operation of adding A for C times. Therefore, by performing encrypted data multiplication for each of the sum operations, an operation can be executed on the encrypted data corresponding to the multiplication of the plaintext data A and the integer C.

Specifically, $e_A \times e_A \times \ldots$, that is, only a power of the encrypted data (power of the integer C) needs to be calculated, as shown in equation (6).

$$e_A \times e_A \times \ldots = e_{A+A+ \ldots} = e_{AC} \tag{6}$$

The e_{AC} shown in equation (6) becomes AC when decrypted, which is a result of the multiplication of the plaintext data A and the integer C. Therefore, it may be seen that an operation of raising the same encrypted data of Paillier encryption is an operation corresponding to the multiplication of the plaintext data and the integer of the plaintext data.

The inference control unit **24** inputs target data **26**, which is data to be processed, to the neural network model **22**, and causes the neural network model **22** to execute the inference processing. In the present embodiment, the target data **26** is encrypted data encrypted by homomorphic encryption.

The storage unit **25** stores the target data **26**, which is a target to be subjected to the inference processing in the neural network model **22** of the inference unit **21**, and the setting value information **27**, which is information related to setting values of coefficients and the like of the neural network model **22**. The setting value included in the setting value information **27** is the learning result of the learning device **10**, and includes, for example, a coefficient or weight of a filter used as a multiplier in the processing unit **23**, or the like. When the inference device **20** executes the inference processing, the inference device **20** may acquire the setting value information **27** from the learning device **10**, store the setting value information in the storage unit **25**, and use the setting value information for the inference processing. The inference device **20** may also store the setting value information **27** learned by the learning device **10** in the storage unit **25** in advance, and then read and use the setting value information **27** from the storage unit **25** when the inference processing is executed. Further, the inference device **20** may also read the setting value information **27** learned by the learning device **10** from a recording medium **111** which will be described below, and store the read setting value information **27** in the storage unit **25**.

The reception unit **28** receives the setting value information transmitted from the learning device **10** and stores the received setting value information in the storage unit **25**. The reception unit **28** receives the encrypted target data **26** transmitted from the client device **30** and stores the received target data **26** in the storage unit **25**.

The inference result transmission unit **29** transmits a result of the inference processing performed by the neural network model **22** of the inference unit **21**, that is, the inference result which is the encrypted data, to the client device **30**.

Next, the client device **30** will be described in detail.

FIG. **4** is a functional configuration diagram of the client device according to the embodiment.

The client device **30** includes a result display unit **31**, a transmission unit **32**, a storage unit **33**, a reception unit **36** serving as an example of a second acquisition unit, a preprocessing unit **37**, and a post-processing unit **38**.

The storage unit **33** stores target data **34**, which is plaintext data for executing an inference processing, and an inference result **35** of the inference processing. The inference result **35** is stored when the inference result is transmitted from the inference device **20** and a predetermined processing is performed, and there is no inference result for the target data **34** which has not been subjected to the inference processing of the inference device **20**.

The preprocessing unit **37** performs a predetermined preprocessing on the target data **34** which is stored in the storage unit **33** and has not been encrypted. Specifically, the preprocessing unit **37** executes a preprocessing of generating encrypted data of homomorphic encryption (for example, Paillier encryption) corresponding to plaintext data obtained by multiplying the target data **34** by a predetermined power of **2** and dividing the same by a cumulative adjustment value included in the processing executed by the inference device **20**. Here, accumulation of the adjustment value used in the processing executed in the inference device **20** is, for example, a value obtained by multiplying all adjustment values used for cumulative multiplication (cumulative adjustment value) when the adjustment values are multiplied cumulatively in the processing. According to this preprocessing, when a subsequent inference processing is executed, components of adjustment performed by the adjustment values are removed from an inference result thereof. Since the accumulation of the adjustment value of the inference processing of the inference device **20** is specified by the configuration of the inference device **20**, the accumulation of the adjustment value may be set in advance in the preprocessing unit **37** or may be acquired from the inference device **20** before the processing and set in the preprocessing unit **37**. The preprocessing unit **37** passes the generated encrypted data to the transmission unit **32**.

The transmission unit **32** transmits the encrypted data passed from the preprocessing unit **37** to the inference device **20** as the target data of the inference processing. The reception unit **36** receives the inference result of the inference processing from the inference device **20** and passes the inference result to the post-processing unit **38**.

The post-processing unit **38** receives the inference result passed from the reception unit **36** and executes a predetermined post-processing on the inference result. Specifically, the post-processing unit **38** performs decrypting corresponding to an encryption method of the preprocessing unit **37**, divides the decrypted inference result by a predetermined power of 2 multiplied by the preprocessing unit **37**, and stores the inference result in the storage unit **33**.

The result display unit **31** displays and outputs various types of information based on the inference result **35** stored in the storage unit **33**. The result display unit **31** may directly display the inference result **35**, or may execute a predetermined processing based on the inference result **35** and display an execution result thereof.

Next, a more specific example of the processing system **1** will be described.

FIG. **5** is a functional configuration diagram of an example of the processing system according to the embodiment.

The learning device **10** includes a processing unit **13-1** constituting a processing layer **1** and a processing unit **13-2** constituting a processing layer **2**.

The processing unit **13-1** performs a multiplication processing of multiplying input data by 0.5. It should be noted that 0.5 is obtained by the learning of the learning device **10** as a setting value to be used in an operation in the processing unit **13-1**. For example, when the plaintext data A is input to the processing unit **13-1**, A×0.5 is calculated in the processing unit **13-1**, and 0.5A is output. The setting value (0.5 in this example), which is learned to be used for the learning processing unit **13-1**, is transmitted to the inference device **20** by the setting value notification unit **18**.

The processing unit **13-2** performs a multiplication processing of multiplying the input data by 0.25 and outputs a result thereof. It should be noted that 0.25 is obtained by the learning of the learning device **10** as a setting value to be used in an operation in the processing unit **13-2**. For example, when 0.5A, which is the plaintext data output from the processing unit **13-1**, is input to the processing unit **13-2**, 0.5A×0.25 is calculated in the processing unit **13-2**, and 0.125A is output. The setting value (0.25 in this example), which is learned to be used for the learning processing unit **13-2**, is transmitted to the inference device **20** by the setting value notification unit **18**.

The inference device **20** includes a processing unit **23-1** constituting the processing layer **1**, a processing unit **23-2** constituting the processing layer **2**, and the inference control unit **24**.

The inference control unit **24** multiplies each setting value transmitted from the learning device **10** by adjustment values corresponding to each of the processing units **23-1**, **23-2** to convert each setting value into an integer, so as to generate adjustment multiplication values and set the adjustment multiplication values in each of the processing units **23-1**, **23-2**. In the present embodiment, the adjustment value is a base of a power to be multiplied by a conversion unit **37***c* (2 in this example) or a value obtained by raising such a base.

In the present example, the adjustment value of the processing unit **23-1** is 4, and the adjustment value of the processing unit **23-2** is 4. In the present example, the inference adjustment unit **24** multiplies the adjustment value 0.5 used for the processing unit **23-1** transmitted from the learning device **10** by the adjustment value 4 of the processing unit **23-1** to generate the adjustment multiplication value 2, and sets the adjustment multiplication value 2 in the processing unit **23-1**. The inference adjustment unit **24** multiplies the adjustment value 0.25 used for the processing unit **23-2** transmitted from the learning device **10** by the adjustment value 4 of the processing unit **23-2** to generate the adjustment multiplication value 1, and sets the adjustment multiplication value 1 in the processing unit **23-2**.

The preprocessing unit **37** of the client device **30** includes the conversion unit **37***c,* an adjustment removal unit **37***b,* and an encrypting unit **37***a.* The conversion unit **37***c* converts floating-point format plaintext data to fixed-point format data by multiplying the floating-point format plaintext data by a predetermined power of 2. Here, the predetermined power of 2 may be, for example, 2^{16} or may be any value that has sufficient number of bits, and may be, for example, a value equal to or larger than the cumulative adjustment value of the inference processing. In the example of FIG. **5**, the conversion unit **37***c* converts data A, which is floating-point format plaintext data, into 2^{16} times, that is, multiplying the data A by 65536 to convert the data A into 65536A.

In order to eliminate an influence of the cumulative adjustment value of the inference device **20**, the adjustment removal unit **37***b* performs a processing of removing a multiple corresponding to the cumulative adjustment value from the target data in advance, that is, a processing of dividing the cumulative adjustment value. In the present embodiment, the adjustment removal unit **37***b* divides the fixed-point format plaintext data, which is converted by the conversion unit **37***c,* by the cumulative adjustment value. In the example of FIG. **5**, the data 65536A is divided by a cumulative adjustment value 16 obtained by multiplying the adjustment value 4 of the processing unit **23-1** and the adjustment value 4 of the processing unit **23-2**, so as to obtain 4096A. The cumulative adjustment value may be received by the adjustment removal unit **37***b* from the inference control unit **24** and thus set, or a user of the client device **30** may acquire and set the cumulative adjustment value.

The encrypting unit **37***a* encrypts the plaintext data by additive homomorphic encryption, for example, Paillier encryption. In the example of FIG. **5**, the plaintext data 4096A is encrypted into encrypted data e_{4096A}. Here, e_{4096A} indicates a value obtained by encrypting the plaintext data 4096A.

In this way, the target data encrypted by performing the preprocessing in the preprocessing unit **37** is transmitted to the inference device **20**. The processing unit **23-1** performs a ciphertext space operation (corresponding operation) on the input encrypted data, the ciphertext space operation corresponding to the processing of multiplying the plaintext data by the set adjustment multiplication value (2 in the same figure). For example, in a case where Paillier encryption is used, the processing unit **23-1** performs an operation of raising the input encrypted data by the adjustment multiplication value as the corresponding operation. In the present example, the processing unit **23-1** calculates and outputs e_{8192A} upon raising the input encrypted data e_{4096A} by the adjustment multiplication value (here, to be squared). When e_{8192A} is decrypted, plaintext data 8192A is obtained. Therefore, an output result of the processing unit **23-1** is the encrypted data e_{8192A}, which is a value of a multiple (here, 16384 times) obtained by multiplying the output result 0.5A of the processing unit **13-1** by the adjustment value (four times), by the power of 2 multiplied by the preprocessing unit **37** (2^{16} times: 65536 times) and by removal adjustment of the cumulative adjustment value ($1/16$).

The processing unit **23-2** performs a ciphertext space operation (corresponding operation) on the input encrypted data, the ciphertext space operation corresponding to the processing of multiplying the plaintext data by the set adjustment multiplication value (1 in the same figure). For example, in the case where Paillier encryption is used, the processing unit **23-2** performs an operation of raising the input encrypted data by the adjustment multiplication value as the corresponding operation. In the present example, the processing unit **23-2** calculates and outputs e_{8192A} upon raising the input encrypted data e_{8192A} by the adjustment multiplication value (multiplied by 1). When e_{8192A} is decrypted, plaintext data 8192A is obtained. Therefore, an output result of the processing unit **23-2** is encrypted data, which is a value of a multiple (here, 65536 times) obtained by multiplying the output result 0.125A of the processing unit **13-2** by the adjustment value of the processing unit **23-1** (4), by the adjustment value of the processing unit **23-2** (4), by the power of 2 multiplied by the preprocessing unit **37** (2^{16} times: 65536 times) and by adjustment of the cumulative adjustment value ($1/16$). Here, the output result of the processing unit **23-2** is the value of the multiple obtained by multiplying the output result 0.125A of the processing unit **13-2** only by the power of 2 multiplied by the preprocessing unit **37** (2^{16} times: 65536 times) and is a value in which an influence of the accumulation of the adjustment value is eliminated. A processing result of the processing unit **23-2** is transmitted to the client device **30** by the inference result transmission unit **29**.

The post-processing unit **38** of the client device **30** includes a decrypting unit **38***a* and a conversion unit **38***b*. The decrypting unit **38***a* acquires an inference result, which is the encrypted data transmitted from the inference device **20**, performs decrypting corresponding to the encryption method of the encrypted data, and passes a plaintext data inference result to the conversion unit **38***b*. For example, in the present example, the decrypting unit **38***a* decrypts e_{8192A}, obtains plaintext data 8192A, and passes 8192A to the conversion unit **38***b*.

The conversion unit **38***b* performs inverse conversion of the conversion unit **37***c* of the preprocessing unit **37**. That is, the conversion unit **38***b* divides fixed-point format plaintext data by a predetermined power of 2, thereby converting the plaintext data into floating-point format plaintext data. In the example of FIG. **5**, the conversion unit **38***b* divides the fixed-point format plaintext data 8192A by 2^{16}, thereby converting the data 8192A to 0.125A. As a result, the client device **30** may obtain the same value as an execution result obtained by executing the processings of the processing units **13-1**, **13-2** of the learning device **10** on the plaintext data.

As described above, in the processing system **1**, the inference device **20** can perform the processing in a confidential state by using the encrypted data, and the client device **30** may obtain the same result as the result of processing the plaintext data.

Next, a processing operation of the processing system **1** according to one embodiment will be described.

FIG. **6** is a sequence diagram showing the operation of the processing system according to the embodiment.

The learning control unit **14** of the learning device **10** uses the learning data **16** stored in the storage unit **15** to cause the neural network model **12** of the learning unit **11** to execute the inference processing, thereby performing learning of various setting values in the processing unit **13** of the neural network model **12** (S**101**). Next, the learning control unit **14** stores setting value information related to the setting values obtained by the learning in the storage unit **15** (S**102**).

Next, the setting value notification unit **18** reads the setting value information **17** stored in the storage unit **15** and transmits the read setting value information **17** to the inference device **20** (S**103**).

The reception unit **28** of the inference device **20** receives the setting value information **17** transmitted from the learning device **10** and stores the received setting value information **17** in the storage unit **25** (S**104**). Next, the inference control unit **24** of the inference device **20** acquires the setting value information **27** from the storage unit **25**, multiplies the setting values in the setting value information **27** for each processing unit **23** by the adjustment values corresponding to each processing unit **23** to convert each setting value into an integer, so as to generate the adjustment multiplication values and set the adjustment multiplication values in each processing unit **23** (S**105**).

Meanwhile, the conversion unit **37***c* of the client device **30** acquires the target data **34** from the storage unit **33**, and converts the target data into a fixed decimal value format (S**106**). Next, the adjustment removal unit **37***b* performs a processing of dividing the fixed decimal value format target data by a multiple corresponding to the cumulative adjustment value (S**107**). Next, the encryption unit **37***a* encrypts the target data obtained by the adjustment removal unit **37***b* by predetermined encryption and passes the encrypted data to the transmission unit **32** (S**108**). The transmission unit **32** transmits the encrypted target data to the inference device **20** (S**109**).

The reception unit **28** of the inference device **20** receives the target data serving as an inference target from the client device **30** and stores the target data in the storage unit **25** (S**110**).

Next, the inference control unit **24** reads the target data **26**, which is encrypted data, from the storage unit **25**, and inputs the target data **26** to the processing unit **23** of a first processing layer (layer 1) of the neural network model **22**. As a result, in the neural network model **22**, the inference processing is executed on the target data **26**, and an inference result is output from the processing unit **23** of a final processing layer (layer N) to the inference result transmission unit **29** (S**111**).

Next, the inference result transmission unit **29** of the inference device **20** transmits the inference result passed from the neural network model **22** to the client device **30** that has requested the inference processing of the target data (S**112**).

The reception unit **36** of the client device **30** receives the inference result from the inference device **20**, passes the inference result to the post-processing unit **38**. The decrypting unit **38***a* of the post-processing unit **38** decrypts the inference result and passes the decrypted inference result to the conversion unit **38***b* (S**113**). The conversion unit **38***b* generates a final inference result (inference result (final)) by executing an inverse conversion of a conversion processing of the conversion unit **37***c* on the decrypted inference result, that is, a processing of returning the inference result from the fixed decimal value format to the floating-point format data (S**114**), and stores the generated inference result (final) **35** in the storage unit **33** (S**115**). Thereafter, the result display unit **31** displays and outputs the inference result based on the inference result **35** stored in the storage unit **33** (S**116**).

As described above, according to the processing system **1** according to the present embodiment, the inference result may be obtained without any problem even when the target data is in the floating-point format. Even when a non-integer multiplication processing is necessary for the plaintext data, the inference device **20** only needs to execute a processing, which corresponds to an integer multiplication processing for the plaintext data, on the encrypted data. Therefore, the inference device **20** may perform the processing including the non-integer multiplication processing for the plaintext while maintaining the confidential state by the encrypted data. As a result, information may be appropriately prevented from leaking from the inference device **20**.

The learning device **10**, the inference device **20**, and the client device **30** may be configured by computer devices.

FIG. **7** is a block diagram showing one embodiment of the computer device. Although the learning device **10**, the inference device **20**, and the client device **30** are configured by different computer devices in the present embodiment, the computer devices may also have the same configuration. In the following description, the computer devices constituting the learning device **10**, the inference device **20**, and the client device **30** will be described using the computer device shown in FIG. **7** for the sake of convenience.

A computer device **100** includes, for example, a central processing unit (CPU) **101**, a main memory **102**, a graphics processing unit (GPU) **103**, a reader writer **104**, a communication interface (communication I/F) **107**, an auxiliary storage device **106**, an input and output interface (input and output I/F) **107**, a display device **108**, and an input device **109**. The CPU **101**, the main memory **102**, the GPU **103**, the reader writer **104**, the communication I/F **105**, the auxiliary storage device **106**, the input and output I/F **107**, and the display device **108** are connected via a bus **110**. The learning device **10**, the inference device **20**, and the client device **30** are configured by appropriately selecting a part or all of constituent elements described in the computer device **100**.

At least one of the main memory **102** or the auxiliary storage device **106** functions as the storage unit **15** of the learning device **10**, the storage unit **25** of the inference device **20**, and the storage unit **33** of the client device **30**.

The CPU **101** of the computer device **100** constituting the learning device **10** performs overall control of the entire learning device **10**. The CPU **101** reads a program stored in the auxiliary storage device **106** into the main memory **102** and executes the program, thereby executing various processings. In the learning device **10**, the CPU **101** configures the neural network model **12** of the learning unit **11**, for example, by executing a processing program stored in the auxiliary storage device **106**. In the computer device **100** constituting the inference device **20**, the CPU **101** configures the neural network model **22** of the inference unit **21**, for example, by executing a processing program stored in the auxiliary storage device **106**. In the computer device **100** constituting the client device **30**, the CPU **101** configures the result display unit **31**, the preprocessing unit **37** and the post-processing unit **38**, for example, by executing a processing program stored in the auxiliary storage device **106**. The CPU **101** of the computer device **100** constituting the inference device **20** may have better processing performance than the CPU **101** of the computer device **100** constituting the client device **30**.

The main memory **102** is, for example, a RAM, a ROM, or the like, and stores a program (a processing program and the like) to be executed by the CPU **101** and various types of information. The auxiliary storage device **106** is, for example, a non-transitory storage device (non-volatile storage device) such as a hard disk drive (HDD) or a solid state drive (SSD), and stores a program to be executed by the CPU **101** and various types of information. In the computer device **100** constituting the learning device **10**, the main memory **102** stores, for example, the learning data **16** and the setting value information **17**. In the computer device **100** constituting the inference device **20**, the main memory **102** stores, for example, the target data **26** and the setting value information **27**. In the computer device **100** constituting the client device **30**, the main memory **102** stores, for example, the target data **34** and the inference result **35**.

The GPU **103** is, for example, a processor suitable for executing a specific processing, such as an image processing, and is suitable for execution of processings performed in parallel, for example. In the present embodiment, the GPU **103** executes a predetermined processing in accordance with an instruction from the CPU **101**. In the computer device **100** constituting the learning device **10**, the GPU **103** may configure at least one processing unit **13**. In the computer device **100** constituting the inference device **20**, the GPU **103** may constitute at least one processing unit **23**.

The reader writer **104** is attachable to and detachable from the recording medium **111**, reads data from the recording medium **111**, and writes data to the recording medium **111**. Examples of the recording medium **111** include non-transitory recording media (non-volatile recording media) such as an SD memory card, FD (floppy disk: registered trademark), CD, DVD, BD (registered trademark) and flash memory. In the present embodiment, a processing program may be stored in the recording medium **111**, and the processing program may be read and used by the reader writer **104**. In the computer device **100** constituting the learning device **10**, the learning data may be stored in the recording medium **111**, and the learning data may be read and used by the read writer **104**. In the computer device **100** constituting the client device **30**, the target data may be stored in the recording medium **111**, and the target data may be read by the read writer **104** and stored in the storage unit **33**.

The communication I/F **105** is connected to the networks **40**, **50**, and transmits and receives data to and from other devices connected to the networks **40**, **50**. For example, the learning device **10** transmits the setting value information to the inference device **20** connected to the network **40** via the communication I/F **105**. The setting value notification unit **18** of the learning device **10**, the reception unit **28** and the inference result transmission unit **29** of the inference device **20**, and the transmission unit **32** and the reception unit **36** of the client device **30** are configured by the communication I/F **105** and the CPU **101** of the computer device **100**.

The input and output I/F **107** is connected to the input device **109**, such as a mouse or a keyboard. In the computer device **100** constituting the learning device **10**, the input and output I/F **107** receives an operation input by an administrator of the learning device **10** by using the input device **109**. In the computer device **100** constituting the inference device **20**, the input and output I/F **107** receives an operation input by an administrator of the inference device **20** by using the input device **109**. Further, in the computer device **100** constituting the client device **30**, the input and output I/F **107** receives an operation input by a user of the client device **30** by using the input device **109**.

The display device **108** is, for example, a display device such as a liquid crystal display, and displays and outputs various types of information.

Next, a processing system **2** according to a modified embodiment will be described.

Here, although only integers of the encryption data may be added to each other in the additive homomorphic encryption, multiplication of integers of the plaintext may be performed by repeating the addition. Therefore, by multiplying an inverse element modulo an order of a cyclic group, to which the encryption data belongs, by a dividend, which is encryption data using the additive homomorphic encryption, division may be performed conditionally. A condition thereof is that the dividend, which is the encryption data, is divisible by a divisor, which is the plaintext. Since the dividend, which is the encrypted data, is encrypted, there is no way to know whether the encrypted data is divisible by the divisor. Therefore, the division cannot always be performed on the additive homomorphic encryption. However, such a fact on the other hand allows division to be performed on space of the additive homomorphic encryption by multiplication of the inverse element if the dividend may be guaranteed to be divisible. In the processing system according to the present modified embodiment, it is possible to guarantee that the dividend is divisible, thereby enabling the division to be performed on the space of the additive homomorphic encryption.

Here, the inverse element of a value (element) of a finite cyclic group to which the plaintext belongs will be described. In order to simplify the description, the inverse element will be described through using an example of a cyclic group G {0, 1, 2, 3, 4} whose order is 5.

An inverse element with respect to a certain element means that a value obtained by multiplying the element by the inverse element is 1. In the cyclic group G, the inverse element 2^{-1} of 2 is $2^{-1}\equiv 3$ (mod5). A reason therefor is that $2\times 3=2+2+2=1$ in the cyclic group G. Here, a ciphertext space operation of the additive homomorphic encryption for an operation of multiplying the plaintext data by the inverse element is $e(D\times 2^{-1})=e(D\times 3)=e(D)\times e(D)\times e(D)=e(D)\hat{}3$. D represents any value of the plaintext data, and e( ) represents data obtained by encrypting the plaintext in the parentheses. Here, when D is divisible by the element (2), $e(D\times 2^{-1})=e(D)\hat{}3=e(D/2)$.

The inverse element with respect to the certain element may be calculated, for example, by using a known extended Euclid's algorithm.

FIG. **8** is a functional configuration diagram of an example of the processing system according to the modified embodiment Portions similar to those of the processing system shown in FIG. **5** are denoted by the same reference numerals, and the description thereof may be omitted.

The processing system **2** according to the modified embodiment includes an inference device **60** instead of the inference device **20** in the processing system **1** shown in FIG. **5**, and includes a client device **70** instead of the client device **30**.

The client device **70** includes a preprocessing unit **39** instead of the preprocessing unit **37**. The preprocessing unit **39** includes the encrypting unit **37***a* and the conversion unit **37***c*.

In the example of FIG. **8**, the conversion unit **37***c* converts data A, which is floating-point format plaintext data, into 2^{16} times, that is, multiplying the data A by 65536 to convert the data A into data 65536A.

The encrypting unit **37***a* encrypts the plaintext data by additive homomorphic encryption, for example, Paillier encryption. In the example of FIG. **8**, the encrypting unit **37***a* encrypts the plaintext data 65536A into encrypted data e65536A.

The inference device **60** includes a processing unit **61-1** instead of the processing unit **23-1**, and includes a processing unit **61-2** instead of the processing unit **23-2**. The processing unit **61-1** performs a ciphertext space operation (corresponding operation) on the input encrypted data, the ciphertext space operation corresponding to the processing of multiplying the plaintext data by the set adjustment multiplication value (2 in the same figure). Further, the processing unit **61-1** performs a ciphertext space operation on the encrypted data obtained by the operation, the ciphertext space operation corresponding to an operation of multiplying an inverse element (4^{-1} in the same figure) of an adjustment value (4 in the same figure) corresponding to an adjustment multiplication value. Here, the ciphertext space operation corresponding to the processing of multiplying the inverse element is a power of an inverse element of ciphertext data (inverse power), and the same ciphertext data must be multiplied for a plurality of times. Therefore, in such an operation, for example, an amount of processing of an operation processing may be reduced by using a binary method, and processing time thereof may be shortened. In the present modified embodiment, since the conversion unit **37***c* of the client device **70** performs a predetermined power of 2, it is guaranteed that a value of the plaintext data is divisible by the adjustment value.

In the example of FIG. **8**, the processing unit **61-1** raises the input encrypted data e65536A by the adjustment multiplication value (here, to be squared). Further, the processing unit **61-1** executes a ciphertext space operation corresponding to the operation of multiplying the obtained encrypted data by the inverse element 4^{-1} of the adjustment value 4, that is, the processing unit **61-1** executes the power of the inverse element 4^{-1} on the encrypted data. As a result, the processing unit **61-1** outputs the encrypted data e_{32768A} corresponding to plaintext 32768A obtained by multiplying the plaintext 65536A by the adjustment value and the inverse element. Therefore, an output result of the processing unit **61-1** is the encrypted data, which is a value obtained by multiplying the output result 0.5A of the processing unit **13-1** by the power of 2 multiplied by the preprocessing unit **37** (2^{16} times: 65536 times).

The processing unit **61-2** performs a ciphertext space operation (corresponding operation) on the input encrypted data, the ciphertext space operation corresponding to the processing of multiplying the plaintext data by the set adjustment multiplication value (1 in the same figure). Further, the processing unit **61-2** executes a ciphertext space operation on the encrypted data obtained by the operation, the ciphertext space operation corresponding to the operation of multiplying the inverse element (4^{-1} in the same figure) of the adjustment value (4 in the same figure) corresponding to the adjustment multiplication value. In the present modified embodiment, since the conversion unit **37**c of the client device **70** performs the predetermined power of 2, it is guaranteed that the value of the plaintext data is divisible by the adjustment value.

In the example of FIG. **8**, the processing unit **61-2** raises the input encrypted data e_{32768A} by the adjustment multiplication value (here, multiplied by 1). Further, the processing unit **61-2** executes a cipher space operation corresponding to the multiplication of multiplying the obtained encrypted data by the inverse element 4^{-1} of the adjustment value 4. That is, the processing unit **61-2** executes the power of the inverse element 4^{-1} on the encrypted data. As a result, the processing unit **61-2** outputs the encrypted data e_{8192A} corresponding to plaintext 8192A obtained by multiplying the plaintext 32768A by the adjustment value and the inverse element. Therefore, an output result of the processing unit **61-2** is the encrypted data, which is a value obtained by multiplying the output result 0.125A of the processing unit **13-1** by the power of 2 multiplied by the preprocessing unit **37** (2^{16} times: 65536 times). As a result, the encrypted data, which is a value obtained by multiplying the power of 2 multiplied by the preprocessing unit **37** (2^{16} times: 65536 times), is transmitted to the client device **70**.

According to the processing system **2**, since the client device **70** does not need to perform the processing of eliminating the influence of the adjustment value used in the inference device **60**, there is no need to change the processing according to the adjustment value in the inference device **60**, and a common configuration may thus be used.

The present invention is not limited to the above-described embodiments, and may be appropriately modified and implemented without departing from the spirit of the present invention.

For example, in the above embodiment, as for the processings of the pre-processing unit **37**, the conversion processing is performed by the conversion unit **37**c, then the adjustment value is corrected by the adjustment removal unit **37**b, and then the encryption of the encrypting unit **37**a is performed. However, the present invention is not limited thereto, and an order of such processings may be changed. However, it may be necessary to change contents of specific processings to be actually performed in accordance with the order of execution to generate the same target data. For example, the encryption processing of the encrypting unit may be executed before the processing of the adjustment removal unit, and in this case, the adjustment removal unit needs to perform the ciphertext space operation corresponding to the processing of multiplying the plaintext corresponding to the processing result of the encrypting unit by the inverse element of the cumulative adjustment value. For example, when the preprocessing unit **37** generates the same target data as the example shown in FIG. **5**, the adjustment removal unit may perform the ciphertext space operation corresponding to the processing of multiplying 16^{-1}. For example, in a case where the target data is an integer, for example, the encryption of the encrypting unit may be performed, and thereafter the conversion processing of the conversion unit may be performed.

In the above embodiment, for example, if the data input to the preprocessing unit **37** is an integer and is guaranteed to be divisible by the cumulative adjustment value, the conversion unit **37**c may not be provided.

In the above modified embodiment, in each layer, the ciphertext space operation, which corresponds to the operation of multiplying the inverse element for removing the adjustment value, is executed. The present invention is not limited thereto, and the ciphertext space processing corresponding to the operation of multiplying the inverse element for removing the adjustment value may be executed in another layer. In a case where the layer of the processing including the adjustment value and the layer of the operation corresponding to the operation of multiplying the inverse element for removing the adjustment value (removal layer) are different layers, correspondence therebetween may be known. For example, the removal layer may be a layer following the processing including the adjustment value. In this way, when the processing of the inference device **60** is modified or changed, a layer to be changed may be easily grasped. In the inference device **60**, if all the influence of the cumulative adjustment value in the processing of the inference device **60** may be eliminated, the processing corresponding to the processing of multiplying the inverse element corresponding to the cumulative adjustment value may be executed once, or a ciphertext space processing corresponding to a processing of separately multiplying inverse elements of a plurality of values obtained by decomposing the cumulative adjustment value may be executed. A ciphertext space processing corresponding to a processing of collectively multiplying a plurality of inverse elements corresponding to adjustment values of a plurality of partial processings may also be executed. The ciphertext space processing corresponding to the multiplication of the inverse element may be executed at the beginning or the end of the processing in the inference device **60**.

Although the conversion unit **37**c performs the multiplication by the power of 2, and the conversion unit **38**b performs the division by the power of 2 in the above-described embodiment, the present invention is not limited thereto. In the present invention, for example, the conversion unit **37**c may perform the multiplication by a power of a number larger than 2, and the conversion unit **38**b may perform the division by the power of the number larger than 2 used in the multiplication. In short, in the present invention, the conversion unit **37**c may perform the multiplication by a power of a number equal to or larger than 2, and the conversion unit **38**b may perform the division by the power of the number equal to or larger than 2 used in the multiplication. Here, for example, when the ciphertext space processing corresponding to the processing of multiplying the encrypted data by the inverse element of the adjustment value is executed as in the configuration shown in FIG. **8**, it is necessary to match a base of the power used by the conversion unit **37**c with a base of the adjustment value. When it is not necessary to execute the ciphertext space processing corresponding to the processing of multiplying the encrypted data by the inverse element of the adjustment value as in the configuration shown in FIG. **5**, the base of the power used by the conversion unit **37**c and the base of the adjustment value may not be matched.

For example, although an example in which the learning device and the inference device perform the processing by using the neural network model including two processing layers (processing units) has been described in the above embodiment, the present invention is not limited thereto. The present disclosure may be similarly applied to a learning device and an inference device that perform the processing by using a neural network model including only one processing layer (processing unit) or a neural network model including three or more processing layers (processing units).

Although an example in which the present invention is applied to the inference device that executes the processing by using the neural network model is described in the above embodiment, the present invention is not limited thereto, and, for example, the present disclosure may be similarly applied to an encryption processing device that executes the processing without using the neural network model.

Although the additive homomorphic encryption is described as an example of the homomorphic encryption in the above embodiment, the present invention is not limited thereto, and fully homomorphic encryption or SomeWhat homomorphic encryption may also be used. LWE lattice encryption may be used as the SomeWhat homomorphic encryption.

In the above embodiment, at least a part of functional units configured by executing the program by the CPU **101** of the learning device **10**, the inference device **20** (**60**), or the client device **30** (**70**) may be configured by other processors in each device or a hardware circuit configured to execute a specific processing. Here, the term "processor" may refer to hardware in a broad sense, and examples of the processor may include general processors such as CPU, dedicated processors such as GPU, ASIC (Application Integrated Circuit), FPGA (Field Programmable Gate Array), and programmable logic device. Here, the term "processor" is so broad that it may include one processor or plural processors in collaboration located physically apart from each other but may work cooperatively. The processing unit **13** configured by the GPU **103** of the learning device **10** may be configured by the CPU **101**, or may be configured by another hardware circuit. The processing unit **23** configured by the GPU **103** of the inference device **20** (**60**) may be configured by the CPU **101**, or may be configured by another hardware circuit.

Although the reception unit **28** is exemplified as an example of the input unit configured to receive target data in the above embodiment, the present invention is not limited thereto, and, for example, a reader writer configured to read the target data from the recording medium where the target data is stored, or a camera configured to capture image data as the target data may be used as the input unit.

Although an example in which the learning device **10** and the inference device **20** (**60**) are configured by different hardware is described in the above embodiment, the present invention is not limited thereto, and such devices may be configured by the same hardware.

Although the encryption data generation device and the processing result utilization device are configured by one client device **30** (**70**) in the above embodiment, the encryption data generation device and the processing result utilization device may be realized by different client devices.

Instead of the adjustment removal unit **37***b* included in the preprocessing unit **37**, an adjustment removal unit **38***c* (not shown) may be provided between the decrypting unit **38***a* and the conversion unit **38***b* in the post-processing unit **38**. In this case, the adjustment removal unit **38***c* performs a processing of dividing an inference result, which plaintext data decrypted by the decrypting unit **38***a*, by the cumulative adjustment value. The adjustment removal unit **38***c* may also be provided in a subsequent stage of the conversion unit **38***b*.

Instead of the adjustment removal unit **37***b* included in the preprocessing unit **37**, the adjustment removal unit **38***c* (not shown) may be provided in a preceding stage of the decrypting unit **38***a* in the post-processing unit **38**. In this case, the adjustment removal unit **37***b* executes the ciphertext space operation corresponding to the processing of multiplying the plaintext corresponding to the inference result, which is encrypted data transmitted from the inference device **20**, by the inverse element of the cumulative adjustment value.

All examples and conditional language recited herein are intended for pedagogical purposes to aid the reader in understanding the invention and the concepts contributed by the inventor to furthering the art, and are to be construed as being without limitation to such specifically recited examples and conditions, nor does the organization of such examples in the specification relate to a depicting of the superiority and inferiority of the invention. Although the embodiments of the present invention have been described in detail, it should be understood that the various changes, substitutions, and alterations could be made hereto without departing from the spirit and scope of the invention.

What is claimed is:

1. An encryption processing system comprising:

an encryption data generation device comprising at least one first processor;

an encryption processing device comprising at least one second processor; and

a processing result utilization device comprising at least one third processor, wherein

the at least one first processor is configured to perform

preprocessing by generating encrypted data of homomorphic encryption corresponding to data obtained by multiplying plaintext data as a target to be processed, by a power of a predetermined number of two or more,

the at least one second processor is configured to perform

acquiring the encrypted data from the encryption data generation device, and

executing a processing on the encrypted data in an encrypted state to obtain a processing result in the encrypted state,

the at least one third processor is configured to perform

acquiring the processing result from the encryption processing device, and

postprocessing by decrypting data of the processing result in the encrypted state and by dividing the decrypted data by the power of the predetermined number of two or more,

the processing executed by the at least one second processor includes at least one partial processing of executing an operation in a ciphertext space corresponding to an operation of multiplying data corresponding to the encrypted data by a multiplier, the multiplier having been converted to an integer by multiplying a predetermined setting value by a predetermined adjustment value, and

the preprocessing performed by the at least one first processor includes generating the encrypted data of homomorphic encryption corresponding to data obtained by dividing multiplied data by accumulation of the adjustment value used in the processing executed by the at least one second processor, the multiplied data being obtained by multiplying the plaintext data as the target to be processed by the power of the predetermined number of two or more.

2. The encryption processing system according to claim **1**, wherein

the preprocessing includes

converting the plaintext data as the target to be processed by multiplying the plaintext data by the power of the predetermined number of two or more,

dividing the converted data by the accumulation of the adjustment value used in the processing executed by the at least one second processor, to obtain adjustment removal data, and

encrypting the adjustment removal data to obtain the encrypted data of homomorphic encryption, and

the adjustment value is a value whose base is the predetermined number of two or more.

3. The encryption processing system according to claim **1**, wherein

the preprocessing includes

converting the plaintext data as the target to be processed by multiplying the plaintext data by the power of the predetermined number of two or more,

encrypting the converted data to obtain the encrypted data of homomorphic encryption, and

executing an operation in the ciphertext space on the encrypted data, the operation corresponding to an operation of multiplying the plaintext data corresponding to the encrypted data by an inverse element corresponding to the accumulation of the adjustment value used in the processing executed by the at least one second processor.

4. An encryption processing system comprising:

an encryption data generation device comprising at least one first processor;

an encryption processing device comprising at least one second processor; and

a processing result utilization device comprising at least one third processor, wherein the at least one first processor is configured to perform

preprocessing by generating encrypted data of homomorphic encryption corresponding to data obtained by multiplying plaintext data as a target to be processed, by a power of a predetermined number of two or more,

the at least one second processor is configured to perform

acquiring the encrypted data from the encryption data generation device, and executing a processing on the encrypted data in an encrypted state to obtain a processing result in the encrypted state, and

the at least one third processor is configured to perform

acquiring the processing result from the encryption processing device, and

postprocessing by decrypting data of the processing result in the encrypted state and by dividing the decrypted data by the power of the predetermined number of two or more,

the processing executed by the at least one second processor includes at least one partial processing of executing an operation in a ciphertext space that corresponds to an operation of multiplying data corresponding to the encrypted data by a multiplier, the multiplier having been converted to an integer by multiplying a predetermined setting value by a predetermined adjustment value, and

the at least one second processor further executes an operation in the ciphertext space that corresponds to an operation of multiplying data corresponding to the encrypted data by an inverse element of a cumulative adjustment value used in the processing executed by the at least one second processor, wherein the cumulative adjustment value is obtained by multiplying all necessary adjustment values used for cumulative multiplication.

5. The encryption processing system according to claim **4**, wherein

the at least one partial processing includes a plurality of partial processings, and

the operation in the ciphertext space executed by the at least one second processor corresponds to an operation of multiplying the data corresponding to the encrypted data by inverse elements each of which corresponds to the adjustment value used in each of the plurality of partial processings collectively.

6. The encryption processing system according to claim **4**, wherein

the processing executed by the at least one second processor includes, the partial processing or in a processing corresponding to the partial processing, the operation in the ciphertext space that corresponds to an operation of multiplying an inverse element corresponding to an adjustment value corresponding to the partial processing.

7. A non-transitory computer readable recording medium storing an encryption processing program causing an encryption processing system including an encryption data generation device having at least one first processor, an encryption processing device having at least one second processor, and a processing result utilization device having at least one third processor to perform an encryption processing comprising:

preprocessing, with the at least one first processor, by generating encrypted data of homomorphic encryption corresponding to data obtained by multiplying plaintext data as a target to be processed, by a power of a predetermined number of two or more;

acquiring, with the at least one second processor, the encrypted data from the encryption data generation device;

executing, with the at least one second processor, a processing on the encrypted data in an encrypted state to obtain a processing result in the encrypted state;

acquiring, with the at least one third processor, the processing result from the encryption processing device; and

postprocessing, with the at least one third processor, by decrypting data of the processing result in the encrypted state and by dividing the decrypted data by the power of the predetermined number of two or more, wherein

the processing executed by the at least one second processor includes at least one partial processing of executing an operation in a ciphertext space corresponding to an operation of multiplying data corresponding to the encrypted data by a multiplier, the multiplier having been converted to an integer by multiplying a predetermined setting value by a predetermined adjustment value, and

the preprocessing performed by the at least one first processor includes generating the encrypted data of homomorphic encryption corresponding to data obtained by dividing multiplied data by accumulation of the adjustment value used in the processing executed by the at least one second processor, the multiplied data being obtained by multiplying the plaintext data as the target to be processed by the power of the predetermined number of two or more.

8. A non-transitory computer readable recording medium storing an encryption processing program causing an encryption processing system including an encryption data generation device having at least one first processor, an encryption processing device having at least one second processor, and a processing result utilization device having at least one third processor to perform an encryption processing comprising:

preprocessing, with the at least one first processor, by generating encrypted data of homomorphic encryption corresponding to data obtained by multiplying plaintext data as a target to be processed, by a power of a predetermined number of two or more;

acquiring, with the at least one second processor, the encrypted data from the encryption data generation device;

executing, with the at least one second processor, a processing on the encrypted data in an encrypted state to obtain a processing result in the encrypted state;

acquiring, with the at least one third processor, the processing result from the encryption processing device; and

postprocessing, with the at least one third processor, by decrypting data of the processing result in the encrypted state and by dividing the decrypted data by the power of the predetermined number of two or more,

wherein the processing executed by the at least one second processor includes at least one partial processing of executing an operation in a ciphertext space that corresponds to an operation of multiplying data corresponding to the encrypted data by a multiplier, the multiplier having been converted to an integer by multiplying a predetermined setting value by a predetermined adjustment value, and

the at least one second processor further executes an operation in the ciphertext space that corresponds to an operation of multiplying data corresponding to the encrypted data by an inverse element of a cumulative adjustment value used in the processing executed by the at least one second processor, wherein the cumulative adjustment value is obtained by multiplying all necessary adjustment values used for cumulative multiplication.

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